Methods for Locating Underground Cable Faults

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Abstract: The cables were mostly laid overhead for a score of years, but the exposed metal wires in cities were easy to be corroded by acid-base gas and water vapor in the atmosphere, which had many hidden dangers. Therefore, more and more places choose to lay cables underground. The underground cable can improve the reliability of the urban power grid and the transmission capacity of urban lines, beautify the urban environment, and improve urban the utilization value of urban land. However, the repair of underground cables is more difficult, need good non-human material and financial resources. Based on the tracking ability, platform stability and maneuverability, this paper is committed to selecting appropriate robots and sensors to locate underground cable faults and reduce the workload of cable maintenance.

1. Introduction

Buried cables occasionally fail for various reasons and in many different ways. Lightning strikes are common causes of shovel overload, surge, or cable damage. Over time, any discontinuity in the cable sheath will corrode the conductor [1][2]. The cable has an open circuit, short circuit, or a fault in between, grounding, and/or another conductor in the cable. Different faults require different methods, therefore, the fault type should be determined.

At present, the existed technologies to deal with faults mainly utilize a single detection method to put forward solutions for a specific fault. In the field environment of underground cables, the fault phenomenon caused by various reasons may be very complex, which often leads to the failure or inaccurate judgment of a single method [3]. It is urgent to comprehensively detect the cable ampacity, partial discharge, dielectric characteristics, and surrounding environmental conditions to obtain comprehensive cable fault information. Meanwhile, for the reason that the fault location cannot be predicted in advance, the mobile cruise mode must be adopted to realize the detection function of the whole line [4]. Generally, traditional methods worked well only if workmen possessed extensive experiences, but the cost of labor force, material, money and time is too high to cultivate skilled workmen. Therefore, a comprehensive intelligent robot, which can detect the underground cable fault, is needed to provide a comprehensive guarantee for cable detection. It detects and predicts underground cable faults using Multi-sensor detection, multi-information fusion, and mobile intelligent inspection [5].

The main work of this paper is to compare and select the robot that can walk and locate the fault position in the pipeline. These robots can replace some electricians to enter the pipeline and carry out fault detection from the outside of the cable. The detection process is like making a gastroscope for the human body, symptoms of any stomach corner can be observed clearly through the probe. Robots can also realize the real-time detection of cable duct state and environment, reduce the heavy tasks of cable detection workers, and solve the problems of difficult detection and high construction safety risk [6].

When selecting a robot, we must consider the operating environment conditions, especially for the adaptability of the robot to complex terrain, traction, obstacle climbing ability. And select the appropriate sensor module according to the data, which help us locate the fault area quickly and accurately.

2. Operational Environment

Sectional drainage will be considered in the construction of the cable trench, and there shall be a good apron slope at the bottom of the trench [7]. The width of each trench must be at least 12 inches. The cover plate of the cable trench is generally a reinforced concrete cover plate, and the cable trench that often needs to be opened indoors is generally a steel cover plate. The whole cable trench is equipped with a continuous grounding wire, and both ends of the grounding wire are connected with the grounding electrode. The metal cable support must be connected with the grounding wire, and all metal components in the trench shall be hot-dip galvanized. When the cable is laid horizontally on the support, the terminals turn and both sides of the cable joint must be fixed. The horizontal spacing of cable supports is usually 0.8m and the vertical spacing is 1m. The bending angle of steel pipe laying is generally not less than 90 °, and the bending radius is not less than 6 times the diameter of steel pipe. If condition is permitted, it can be 10 times the diameter of the steel pipe. When the exposed pipe laying has only one bending, it can be bent for 4 times. The steel pipe and beam joint should be firmly connected and coated with anti-corrosion grease. The steel pipes at both ends of the beam joint should have a reliable electrical connection.

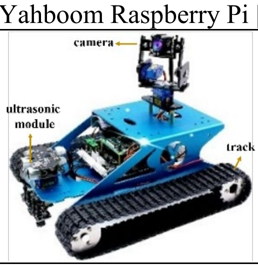
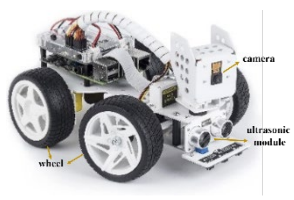
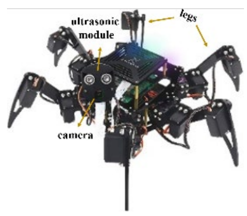
Due to the complex cable duct environment, the robot may encounter some small obstacles when traveling along the cable, such as splicing and cable installation support, which must be negotiated. Although the overall height is limited, the space available for payloads (e.g. sensors) along the length of the cable is very flexible, so the robot can achieve a very comprehensive detection work

On the other hand, reliable communication inside and outside the metal pipeline is also a worthy problem. Sankaran S. et al. summarized that to solve the shielding effect of metal pipe walls, the extremely low-frequency electromagnetic pulse can be used to transmit information [8]. According to the pipeline global positioning system, it is used as a long-distance tracking and near-field positioning system. The design method is introduced and the communication protocol is formulated. A location algorithm based on a database query is proposed, which has also been verified in the field test and can be applied to the autonomous motion and detection of variations in pipe robots. The problem that the metal tube will affect the communication has been solved.

3. Comparison of Robotic Platforms

Common small robots include wheeled robots, tracked robots, hexapod robots, and etc. Now select these three robots for analysis and comparison, including size, weight, price, and sensors, as shown in Table 1.

Table 1 Parameters of three common robotic platforms

brand	Yahboom Raspberry Pi [9]	SunFounder [10]	Freenove [11]
picture			
sensors	camera, light, ultrasonic	camera, line-tracking, ultrasonic	camera, light, ultrasonic
weight(kg)	1.5	0.84	2.76
dimensions (L×W×H) (cm)	25×15×10	21.5×14.5×12	28×26×9
moving modes	treads	wheels	legs
cost ($)	138	110	169

(1) Treads robot

The treads robot in Table 1 is from Yahboom. This robot kit consists of an aluminum alloy solid chassis, two high-power motors, metal coupling, crawler, multifunctional expansion board, and various sensors, which is equipped with a camera (480p) that can transmit high-definition video in real-time, a searchlight for lighting, an ultrasonic module, and a four-way patrol module [9]. It can perform a series of other artificial intelligence functions such as difficult route tracking and ultrasonic obstacle avoidance. At the same time, it has a small volume and lightweight and can enter the underground cable track.

Compared with wheels, the treads robot has high performance and an optimized traction system, which is an advantage in power transmission efficiency. Even on smooth surfaces such as snow or wet concrete, it can have high traction and can run on rough terrain, and the wheels may get stuck. Robots moving on tracks have lower psi on the ground. This means less impact on the ground, especially when the robot is heavy.

However, considering its disadvantages, the treads robot has low speed and poor mobility on the track. It needs more power when turning and is not flexible. In addition, continuous tracks are easier to damage than wheels and more difficult to repair and replace [9].

(2) Wheels robot

The wheels robot in Table 1 is from SunFounder which is also composed of solid aluminum alloy materials and multiple sensors, including a PTZ camera, ultrasonic module, and line tracking module, and can perform intelligent obstacle avoidance, object tracking, line tracking, and visual recognition functions. It also integrates motor drive, servo drive, and preset ADC, PWM, digital pins for function expansion. Therefore, it is more convenient for us to add the required functions. It is also the smallest and least expensive of all robots.

Wheels robots have low production costs, move quickly and turn flexibly, which are lighter than other types of robots. However, the wheeled robot also has fatal disadvantages, its obstacle crossing ability and stability are poor. However, in the underground cable laying environment, our robot car needs to pass through many obstacles, large and small. If the wheel wants to cross the obstacles, its wheels height must be at least twice of the vertical obstacles. This makes it very difficult to walk in underground cable pipelines.

(3) Legs robot

The hexapod robot in Table 1 is from Freemove. It has multiple sensor components. In addition to an LED lighting module, a camera, and an ultrasonic module, it also has multiple servo systems and a gyroscope module to make the robot more accurate as in figure 1 [11]. Its weight is 2.76kg, and the size of 28 x 26 x 9 (cm) is larger than the other two robots, but it is still within the acceptable range.

The hexapod robot has good characteristics of learning from the principle of insect crawling [12]. With the development of science and technology, the stability and accuracy of robot motion have been greatly improved. The traditional crawler robot has the advantages of simple structure, large traction, and not being easy to slip. It works efficiently on flat roads and can play a great role, but it plays little role in dealing with extreme conditions. However, the hexapod bionic robot has a limb structure similar to the spider and also has some physiological characteristics and travel characteristics of the spider. The physiological characteristics include its small contact area with the ground, which makes it easier to find the focus and more stable in the movement process. And it can move smoothly in an environment that is not suitable for the movement of most crawler and wheeled robots, it can better adapt to the complex underground pipeline environment and also work in it.

4. Sensor Selection

Because the environment for laying cables is complex and changeable, and there are often sundries such as ponding, insects, and mice, the fault detection of underground cables needs to collect video, temperature, and sound signals, then transmit them to the ground control host, to master the real-time situation of cable detection. Therefore, to complete the detection task, we need suitable robots and temperature sensors, handheld computers, ultrasonic modules, camera monitoring devices, etc. In addition, we can judge the short circuit fault by detecting whether the circuit is continuous through the signal generator and microcontroller system [13].

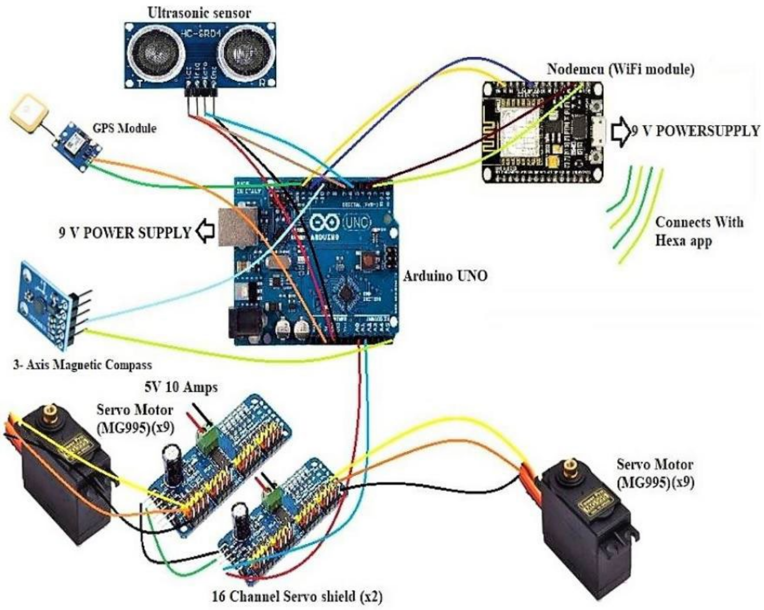


Fig.1 The Circuit Diagram of Hexapod, Connecting All the Components [11]

4.1 Lighting Module

The underground cable trench is very dark. To make the video detection module visible, it must be equipped with good lighting facilities, such as LED lights or searchlights.

4.2 Camera

Through the camera, we can see the external damage to the cable, such as the cable shell being bitten by insects and mice or the damage caused by external pressure and impact. And whether there are sundries and ponding around the cable that may endanger the safety of the cable.

4.3 Temperature Sensor

The temperature sensor can measure the surface temperature of the cable. If the temperature is too high and other modules are normal, it can be judged that there may be potential safety hazards in the cable here, which should be checked in time. If the microcontroller's analog input is also abnormal, consider the abnormal discharge of the cable here.

4.4 Signal Generator and Microcontroller Module

This method uses the principle of Faraday electromagnetic induction, generates a 3kHz low-frequency signal through the signal generator, generates a magnetic field around the wire, and is induced by the robot using the inductor circuit. When the robot reaches the discontinuity point, the magnetic field will be zero, the analog input value of the microcontroller will become very small, and the robot will detect the short circuit and transmit the information to the ground host.

5. Conclusion

Through analysis of tracked robots, wheeled robots, and hexapod robots, it can be concluded that the tracked robot has high traction and is suitable for driving on soft and muddy roads, but the speed is slow, the efficiency is low and the damage is difficult to be repaired. The wheeled robot is more suitable for driving on smooth roads and cannot adapt to the roads with more underground obstacles and complex environments, while the hexapod robot has strong obstacle climbing ability, Flexible turning, and strong adaptability to complex terrain, and good stability. In addition, although the hexapod robot has a higher price and larger volume, it can be found that its value is still in an acceptable range through comparison. Therefore, considering the actual environment of the underground cable trench, the hexapod robot is selected in this paper.

In terms of sensors, according to the actual situation, we suggest that the robot should have cameras, LED lights, temperature sensors, signal generators, microcontrollers, and mobile computer control terminals. The device can shorten the outage time and even design the non-outage maintenance of cables, to reduce the outage loss, improve the maintenance efficiency, avoid hidden troubles effectively, and have high-cost performance.

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